International Journal of Mechanical Engineering and Technology (IJMET)
Volume 8, Issue 2, February 2017, pp. 176–182 Article ID: IJMET_08_02_021
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=2
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

THERMAL PERFORMANCE AND ECONOMICS ANALYSIS OF DOUBLE FLOW PACKED BED SOLAR AIR HEATER

Saket Kumar, R.K. Prasad and K.D.P. Singh
Research Scholar, Department of Mechanical Engineering, N.I.T. Jamshedpur, India

ABSTRACT

Solar air heater is a type of heat exchanger that transforms solar radiation energy into heat energy. Conventional solar air heaters have poor thermal performance due to high heat losses and low convective heat transfer coefficient between absorber and flowing air. Attempts have been made to improve the thermal performance of conventional solar air heater by employing various design and flow arrangements. Double flow solar air heater with packing is an important and effective design improvement that has been proposed to improve the thermal performance. This paper presents the performance and economic analysis of double flow solar air collector with and without packing in the duct. Effect of various parameters on the thermal performance and pressure drop characteristics has been studied experimentally. The study concludes that double flow arrangement with packing is economical and having short payback period. Also, the thermal performance of double flow solar air heater with packing in upper duct is significantly higher compared to double flow solar air heater without packing and conventional solar air heater.

Key words: Solar air heater, solar energy, air temperature, heat exchanger, thermal Analysis

Cite this Article: Saket Kumar, R.K. Prasad and K.D.P. Singh. Thermal Performance and Economics Analysis of Double Flow Packed Bed Solar Air Heater. *International Journal of Mechanical Engineering and Technology*, 8(2), 2017, pp. 176–182.
http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=8&IType=2

1. INTRODUCTION

Solar energy is the most important amongst the renewable energy sources due to its quantitative abundance, its capacity to overcome the energy crisis and environmental threat caused by the continuous use of fossil fuels on a very large scale. Conventional solar air collectors have poor thermal efficiency primarily due to high heat losses and low convective heat transfer coefficient between the absorber plate and flowing air stream, leading to higher absorber plate temperature and greater thermal losses. Attempts have been made by different investigators to improve the thermal performance of conventional solar air collectors by employing various design and flow arrangements. Dhiman et.al.[1] presented the counter and parallel flow packed bed solar air heaters theoretically and experimentally and investigated the effect of air mass flow rates and bed porosity on the thermal and thermo hydraulic efficiencies of the parallel and counter flow packed bed solar air heaters. Prasant [2] established the effect of differential air mass flow rate on the thermal performance of parallel pass packed bed solar air heater. Chabane et.al.[3] developed experimentally the analysis on the thermal performance of a

solar air collector with longitudinal fins in a region of Biskra, Algeria and studied that the effects of mass flow rate of air on the outlet temperature, the heat transfer in the thickness of the solar collector and thermal efficiency. Gupta et.al. [4] analysed the performance and economic conditions of double pass solar air collectors with and without porous material. Effects of various parameters on the pressure drop and thermal performance characteristics have been studied experimentally. This work concludes that double pass arranged with porous material is economical and having short payback period. Choudhury et al.[5] studied theoretically the ratio of the annual cost and the annual energy gain for two pass solar air heaters with single and double covers above the absorber plate. Ozen et.al.[6], investigated experimentally the thermal performance of a double flow solar air heater having aluminium cans and studied experimentally that a device for inserting an absorbing plate made of aluminium cans into the double pass channel in a flat plate solar air heaters, which improves the collector efficiency by increasing the fluid velocity and enhancing the heat transfer coefficient between the absorber plate and air. Prasad et al,[7], established an experimental investigation that a packed bed solar air heater using wire mesh as packing material and compared well with conventional solar air heater, which results the thermal efficiency of a packed bed solar air heater using wire mesh as packing material increase in the range of 76.9 to 89.5% than the conventional one.

This paper presents the economical and performance analysis of double flow solar air collector with porous material. It is concluded that the double flow with packed bed arrangement is economical with relatively short payback period. It is also observed that the thermal performance of double flow with packed bed is significantly higher compared to single pass conventional arrangement.

2. METHODOLOGY

2.1. Experimental Set-up

The experimental set up has been designed and fabricated for the experimentation using wire screen as packing material in the upper duct of double flow solar air heater and shown in Fig.1. The total length of the rectangular duct is 3250 mm in which the flow straightener is of 1000 mm and the test section is of 2250 mm as shown in Fig1. The main components of the experimental set up are halogen lamp, wooden rectangular double duct, comprising flow straightener and test section, G.I pipes, blower, Control valve, orifice meter, U-tube manometer and thermocouple etc. The internal dimensions of both the lower and upper duct are 2250 mm× 400 mm ×30 mm. The indoor experiment was conducted by using a halogen lamp as the source of radiation energy. The various positions of the thermocouples to measure air temperature are shown in Fig.2.

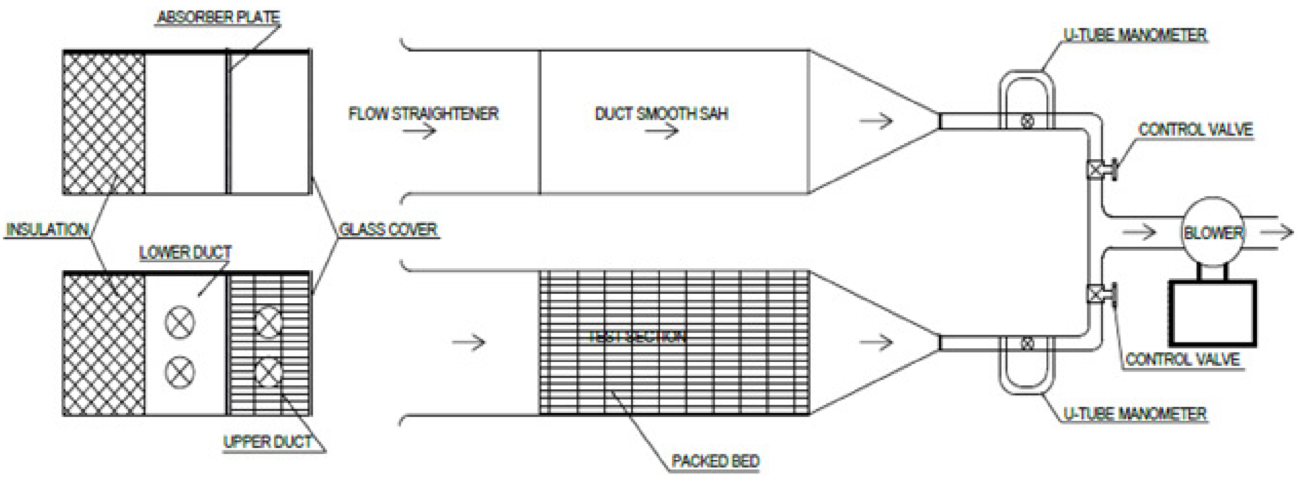


Figure 1 Schematic diagram of Experimental set up of a double flow packed bed solar air heater.

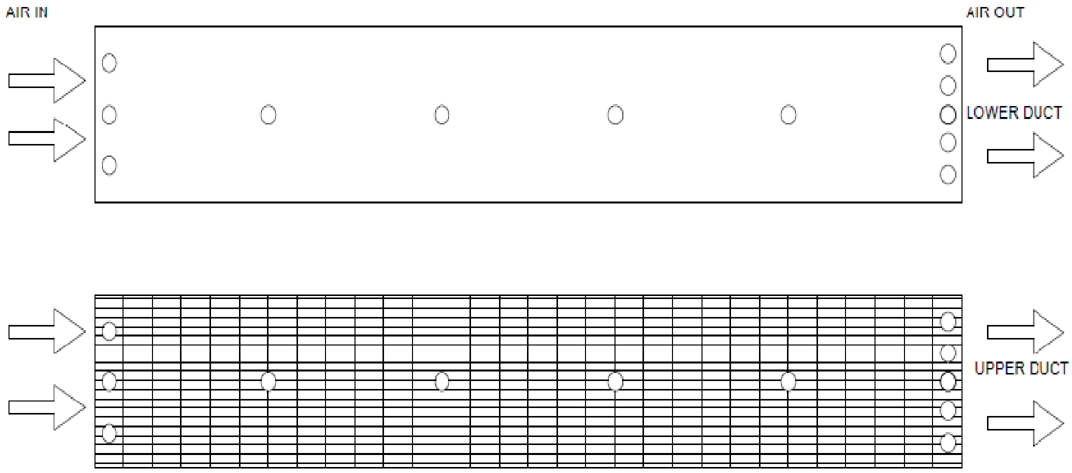
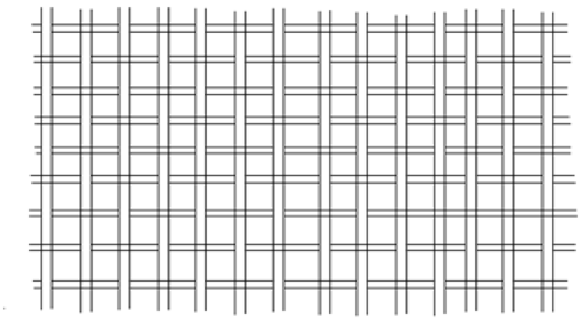


Figure 2 Positions of thermocouples to measure the air temperature in the test sections.

2.2. Experimentation

In order to collect data, experiments were conducted on the set up which have a double flow solar air heater with wire mesh packing in its upper duct and a smooth absorber plate of conventional type solar air heater. A view of wire mesh is shown in Fig.3. In this study the effect of packing height on the upper duct has been examined on the air temperature rise parameter and thermal efficiency. For a given height of wire screens, the mass flow rate has been varied and outlet temperatures have been measured by thermocouples. After the inspection of correct functioning of all the instruments and the leak proof of the joints the blower is now switched on. Five values of mass flow rates were considered for each height of wire mesh packing. The mass flow rate of air has been varied with the help of control valves. The mass flow rate in upper duct is fixed as 0.25M and the mass flow rate in lower duct is fixed as 0.75M, where M is the total mass flow rate of air. After fixing the total mass flow rate at different fractions, the various values were recorded when the system is at quasi-steady state.



Geometry of wire mesh
Wire diameter = 0.504 mm
Mesh per inch=10 x 10 mm
Longitudinal Pitch/ Transverse Pitch =2.54 cm

Figure 3 A view of wire mesh screen.

2.3. Performance Analysis

The experimental data have been used to determine desired parameters as discussed below. All the properties of air have been evaluated at the mean temperature of air from inlet to outlet.

The useful energy gain, $Q_u$is given as [Duffie and Beckman]

$$Q_u = \dot{m} c_p \left(T_{out} - T_{in}\right) \tag{1}$$

Also, thermal efficiency can be given as

$$\eta = \frac{\dot{m}c_p\left(T_{out} - T_{in}\right)}{I \times A_c} \quad (2)$$

Porosity of the packed bed is defined as

$$\rho = \frac{V_t - V_s}{V_t} \quad (3)$$

2.4. Economic Analysis

2.4.1. Annual Cost

In order to estimate the annual cost (AC) of the solar air heaters per unit surface area, the different cost factors are calculated as given below [5]:

Annual pumping cost= $APC = \left(\dot{m}.\Delta P / \rho\right) t_{op} CE$ (4)

Where,

$\dot{m}$ = mass flow rate (kg/s)

ρ = density of air (kg/m^3)

t_{OP}= operational time

And the pressure drop (ΔP) across each flow channel is

$$\Delta P = F\left(\dot{m}^2 / \rho\right)\left(L / D\right)^3 \quad (5)$$

and,

$F = F_0 + \left(D/L\right)$

$F_o = 24/R_e$

$r = 0.9$ for $R_e < 2500$

$F_o = 0.0094$, $r = 2.92 R_e^{0.15}$ for $2500 < R_e < 10^4$

$F_0 = 0.059 R_e^{-0.2}$, $r = 0.93$ for $10^4 < R_e < 10^5$

The cost of electricity (CE) is considered to be Rs. 1.50 KWH

Annual collector cost (ACC) =CRF× CI

Where,

Capital investment (CI)= Material cost+ Paint cost+ Fabrication cost

And, Capital recovery factor (CRF)= $i\,(i+1)^N/[(i+1)^N-1]$

The cost of black absorbing paint is assumed as Rs.50/m^2, cover as Rs.125/m^2, air- duct material as Rs. 160/ m^2 for the rear, side plates as Rs.130/m^2 and insulation as Rs.80/m^2. The interest rate (i) is assumed as 10% and collector life (N) as 10year. The fabrication cost and the profit are each considered to be 25% of the cost of the capital investment.

The maintenance cost (MC) of the collector is considered to be 10% of ACC.

Annual salvage value (ASV) = SFF× SV

Where, Salvage fund Factor (SFF) =$i[(i+1)^N -1]$

Salvage value (SV) = 0.1 CI

The annual cost of the collector (AC) in Rs./ m^2 is then calculated as

AC =ASV-ACC+MC+APC

The payback period of double flow arrangement with packing in the solar collector can be determined from [8]

$$n = \frac{\ln\left[\left(\frac{i_f C}{C_f FE}\right)+1\right]}{\ln\left(i_f+1\right)} \tag{6}$$

Where,

I_f= rate of increment every year

C=cost in rupees

FE= fractional annual saving

C_f= cost of fuel

3. RESULT AND DISCUSSION

In the following section, results of an experimental investigation on thermal performance of a double flow packed bed solar air heater with packing in upper duct are presented. The various parameters were calculated using Equations. 1-3 by taking the following base/ range values of bed geometry and operating parameters and different graphs were plotted as given in Fig.4-6.

I= 900 W/m^2, W=400 mm, L= 2250 mm, H= 30 mm, ṁ=0.0164 - 0.0362 kg/s, Bed height= 5 - 25 mm.

Fig.4 shows the variation of rise in temperature of air along the duct with mass flow rate for different bed height. The rise in air temperature is higher at the lower mass flow rate and decreases with increase in mass flow rate. This trend of variation is observed for all heights. For a given bed height air temperature falls steeply with the increase in total mass flow rate. At higher mass flow rate there is less effect of wire mesh packing on the air temperature rise because all the curves tend to converge at high flow rates. As expected the rise in air temperature is the lowest for smooth plate solar air heater. A maximum enhancement of 2.03 in the air temperature has been achieved with the double flow packed bed solar air heater over a smooth absorber plate of conventional type solar air heater

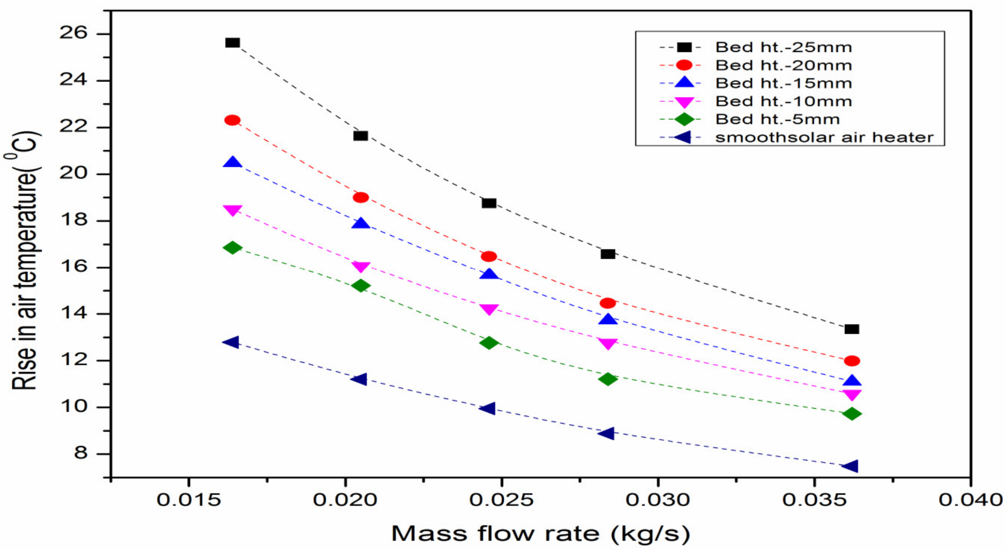


Figure 4 Variation of Rise in air temperature with mass flow rate of air for different bed height.

The values of thermal efficiency corresponding to total mass flow rate for the different bed height are plotted in Fig.5.The curves show that as the bed height increases the thermal efficiency of the collector increases. This is because of large total depth of bed compensate for the increase in volumetric heat transfer coefficient by adding heat transfer area because higher regions of bed materials for such a system is more effective for heat transfer.

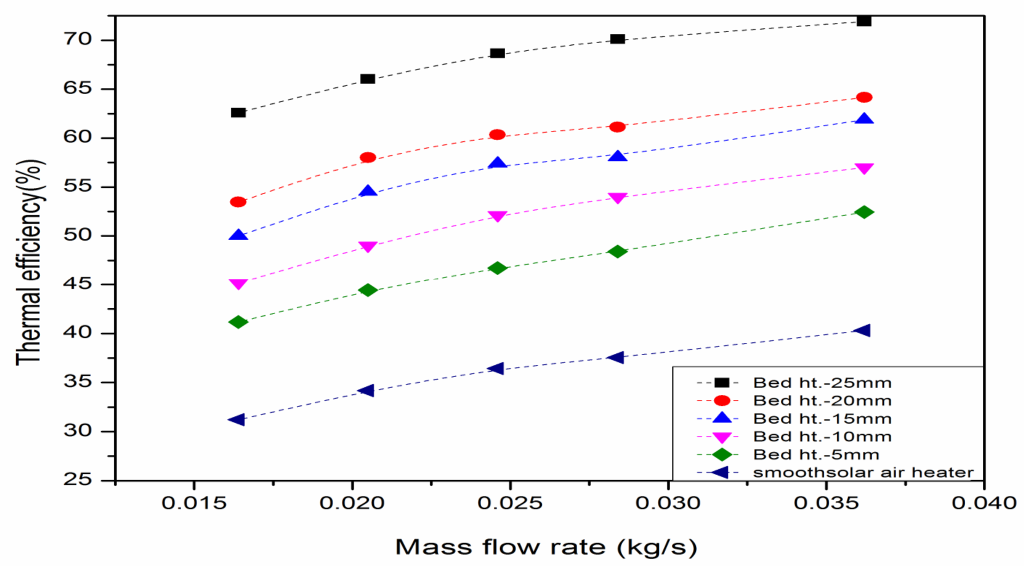


Figure 5 Variation of Thermal efficiency with mass flow rate of air for various bed height.

An important factor that has to be considered when employing porous material for the purpose of enhancing heat transfer rate is the penalty arising from the increased pressure drop. In the present investigation pressure drop has been measured with help of inclined U-tube manometer for all the experimental runs. Experimental data have been obtained for pressure drop for different flow conditions and presented in the Figure 6. It has been observed that the pressure drop increases from 8.4 N/m2 to 38.2 N/m2 for the plane solar air heater when mass flow changes from 0.0164 to 0.0362 kg/s. The corresponding values for the double flow packed bed are 10.42 to131.13N/m^2. It has been further observed that the magnitude of pressure drop is not high for lower mass velocity even for lower porosity, while pressure drop is considerably higher for higher mass velocity even for higher porosity.

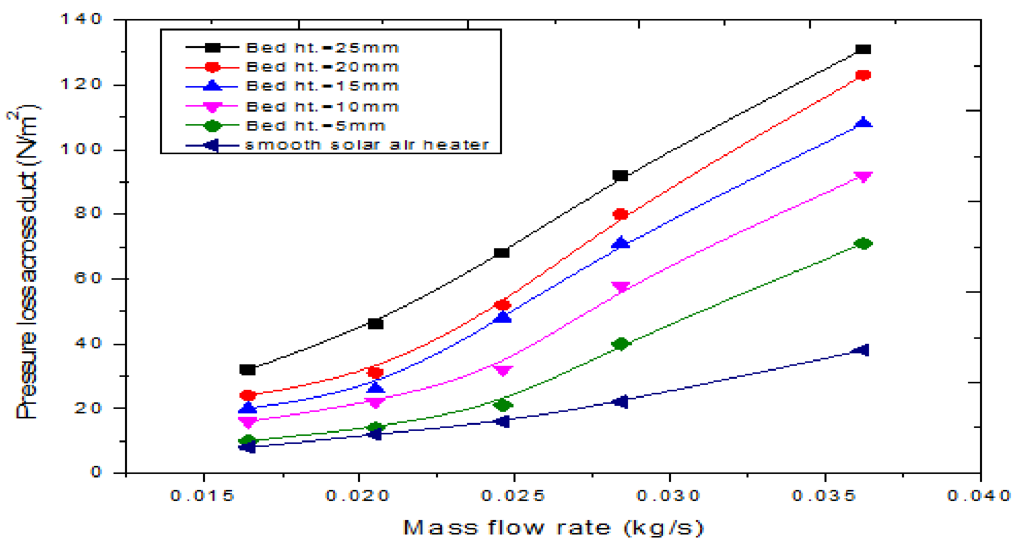


Figure 6 Variation of mass flow rate with pressure loss across duct for various bed height.

4. CONCLUSION

- An enhancement in the thermal efficiency and temperature rise parameter of double flow collector having its upper duct packed with wire mesh absorber can be obtained up to 1.51 and 2.03 respectively corresponding to a given height of packing and mass flow rate of air in the duct.
- The rise in air temperature in the bed has been found to be a function of total bed depth. It increases with the height of packed bed depth.
- The thermal efficiency of the collector has strong dependence on system and operating parameters. It increases with the increases in packing height.
- Double flow arrangement with packing in economic with payback period less than 3 years.

REFERENCES

[1] Dhiman Prashant, Thakur N.S., Chauhan S.R.,2012. Thermal and thermohy draulic performance of counter and parallel flow packedbed solar air heaters. Renewable Energy 46,259-268.

[2] Prashant Kumar,2012. Effect of Differential Mass Flow Rate on the Thermal Performance of Double Duct Packed Bed Solar Air Heaters. International Conference on Renewable Energies and Power Quality.

[3] Chabane Foued, Moummi Noureddine, Benramache Said, 2013.Experimental analysis on thermal performance of a solar air collector with longitudinal fins in a region of Biskra, Algeria. Journal of Power Technologies 93, 52–58.

[4] Gupta Akliesh and kumar Ravi, Ramani Bharat,2011. Performance and economic analysis of double pass solar air collector. International Conference on Energy Sustainability.

[5] Choudhury C ,Chauhan M, Garg H. P. ,1995**.** Performance and cost analysis of two-pass solar air heaters. Heat Recovery Systems & CHP 8,755-773.

[6] Ozgen Filiz, Esen Mehmet, Esen Hikmet, 2009.Experimental investigation of thermal performance of a double-flow solar air heater having aluminium cans. Renewable Energy 34, 2391–2398.

[7] Prasad S.B., Saini J.S., Singh Krishna M.,2009.Investigation of heat transfer and friction characteristics of packed bed solar air heater using wire mesh as packing material. Solar Energy 83,773–783.

[8] Duffie J.A and Beckman W.A, 1980. Solar Engineering of Thermal Processes, New York: Wiley.

[9] Ravish Kumar Srivastava and Ajeet Kumar Rai, Studies on the Thermal Performance of a Solar Air Heater. *International Journal of Mechanical Engineering and Technology*, 7(6), 2016, pp. 518–527.

[10] Abdulsalam D.Mohamed, Aamer M.Al-Dabagh and Duaa A.Diab, Experimental and Theortical Study of the Thermal Performance of Heat Pipe Heat Exchanger. *International Journal of Mechanical Engineering and Technology (IJMET),* 7(3), 2016, pp. 86–101.